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PERFORMANCE OF THREE-BLADED ARCHIMEDES SCREW TURBINE

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ABSTRACT

The study of Archimedes screw turbine as a micro-hydro power-plant is being developed in this decade. Screw turbine has some advantages, namely no need draft-tube, fish-friendly, and can be operated in low head (H<10 m). The aim of this research is to recognize the performance of Archimedes screw turbine due to flow rate effect and its slope and also to reveal flow phenomenon that occurred among blades of the screws. Physical model of the screw turbine was made with acrylic as represented laboratory scale. Geometrical shapes are three blades, screw angle of 30^0, ratio radius of 0.54, pitch of 2.4Ro. Measured and observed variables are turbine's rotation, torsion, and flow visualization with inlet flow rate variable (c_0) are 0.3 m/s, 0.4 m/s, and 0.5 m/s, respectively. And the turbine's slope variables (α) are 25^0, 35^0, and 45^0. According to experimental data, the maximum turbine efficiency is 89% that occur at 0.5 m/s of flow rate and 25^0 of shaft slope. The result of this research reveals that the largest hydraulic power occurs in the turbine shaft's slope (α) of 45^0 in the amount of 16.97 with turbine's rotation of 350 rpm. Output power of screw turbine occurs in the turbine shaft's slope (α) of 45^0 in the amount of 5.11 watt and rotation of 182 rpm. The highest efficiency is 89% occur in turbine's rotation of 50 rpm in the turbine shaft's slope of 25^0 with $y = 1R_0$. The result of this study show that the performance of the screw turbine is more maximum on the lower shaft's slope that automatically become better operating in low head and rotation.

Keywords: performance, screw turbine, power, efficiency.

INTRODUCTION

The need of electrical power increases as the growth of population. In otherwise, electrical power that produced by electric company is still not sufficient for Indonesian people. Therefore, the study of energy source exploration, especially renewable energy, is important to develop in Indonesia, which has a lot of river stream and irrigation channels. The river stream and irrigation channels are a potential source to build micro-hydro power-plant. Many types of water turbines had been applied; they are cross-flow, kaplan, propeller, turgo, francis, and pelton. The screw turbine is one type of water turbine that recently studied in this decade. The advantages of screw turbine are low head operated (H<10 m), no need draft tube, easy maintenance and fish-friendly (David KilamaOkot, 2013). The screw turbine is classified as reaction turbine, which operated in low head (ElbatranA.H, *et al*, 2014). The kinetic and potential energy of water flow is changed into mechanical energy through the blade of the screw; finally it turns a turbine shaft that produces electrical power by generator via a transmission. The specific weight of water on the blades causes the screw to rotate. By assumption, there is no loss in overall potential energy, hence it will result maximum efficiency of 100% (Müeller Gerald 2009).

Some researchers had developed a study on Archimedes screw, among others, the numerical optimization of screw geometric (Rorres, 2000). He stated that the optimum ratio of pitch depends on the number of blades and the radius ratio (R_1/R_0) is equal to 0.54. Then, Müelleret all simplified the theory of Archimedes screw based on geometrical parameters and ideal energy conversion process for one helix turn. They stated the efficiency of the screw turbine is influenced by geometric shape and its flow losses. The analytical model of inlet flow in the screw turbine, by taking into account the leak flow in the gap between the screw and outer cylinder (casing), and also excessive water in the center of the pipe had been studied (Nuernbergk et all, 2013). Matlab simulation of the screw turbine for power-plant of low head had been conducted (Ali Raza et all, 2013). In their research, they compared modeling and theoritical (Müeller*et al* 2009 and Nuembergk*et al*, 2013) with theory (Brada *et al*, 1996a and 1996b). Furthermore, Havendry Adly and Hendro Lius (2010) investigated of optimum screw angle on screw turbine with variations from 23^0, 26^0, and 29^0. They reported that in the angle of 29^0 produce better of power and efficiency than in an angle of 23^0 and 26^0. And then, Hizhar Yul (2011) studied about the influence of pitch and shaft's slope on the performance of two blade screw turbine with low head. His research explained that on the pitch of 2Ro produces rotation velocity higher than pitch of 1.6Ro and 1.2Ro. And the largest power happens to the shaft's slope of 35^0 compared with 25^0, 30^0, and 40^0.

The Archimedes screw turbine is applied in the river, irrigation channel which they are open channel condition. The prime mover force of the open channel is weight of fluid due to gravity, and its pressure distribution is hydrostatic. Property of open channel could be recognized via number parameters dimensionless, namely Froude (*Fr*). The focus of this research is about fluid flow among screw blades which affected by the characteristic length of Froude number (*Fr*), in this case, that is similar with the depth flow inlet, inlet flow velocity, and shaft's slope. Flow phenomena among screw blade is the important factor in screw turbine power-plant, because water flow is a source of kinetic and potential energy that is used in the system of screw turbine power-plant. The screw turbine was made with laboratory scale, of acrylic.

ARPN Journal of Engineering and Applied Sciences

The aim of this research is to recognize the efficiency of screw turbine that is observed by Froude number effect.

EXPERIMENTAL METHOD

This research experimentals had been done by constructing Archimedes screw turbine model as shown in Figure-1, then test installation was installed in laboratory scale with the layout as Figure-2 (Tineke Saroinsong et all, 2015). The working fluid is fresh water. Material of the screw was made from acrylic, the geometry of three-bladed with seven screws (m = 21helix turn), diameter of the pipe as shaft is 60 mm, height of blade is 25 mm, pitch of 2.4Ro, radius ratio (R_1/R_0) of 0.54 and the blade angle of 30^0.

The data were collected with the following sequence. The first of all, setting the installation according to the parameters and calibrated instruments. Test runs of water flow from a reservoir tank via pump to the first tank with controlled flow rate via the valve. After that, water was flown to the secondary tank through pipe installation. In this tank water was kept in steady state condition. Furthermore, the outlet flow velocity from secondary tank that run to rectangular duct was varied by a sluice gate. Characteristic length (y) was controlled in sluice gate and measured at the end of inlet turbine. Next, the water flowing through turbine and created rotation of the blades and finally water came back to the reservoir tank. After all, data collecting process were conducted by controlling the shaft's slope (α), to control characteristic length variabels (y) with a sluice gate mechanism so that still in a steady state condition. Measurement data that had been taken were turbine rotation (n) with tachometer, flow visualization with digital camera, and torsion with prony. Position of prony is perpendicular with turbine shaft which is connected with pulley and belt. Flow rate data (Q) were from volume per helix turn (Vu) that equal with rotation (n/60) added by the flow rate of water between screw blade and casing (leak fraction Q_G/Q_W of 0.02 and 0.06). Measurement data were taken from each characteristic length (y) of 1Ro, 2/3Ro, and 1/2Ro with varied inlet flow velocity of 0.3 m/s, 0.4 m/s, and 0.5 m/s and with varied shaft's slope (α) of 25^0, 35^0, and 45^0. All measurement data was replied three times in each variable, and then mean value was taken.

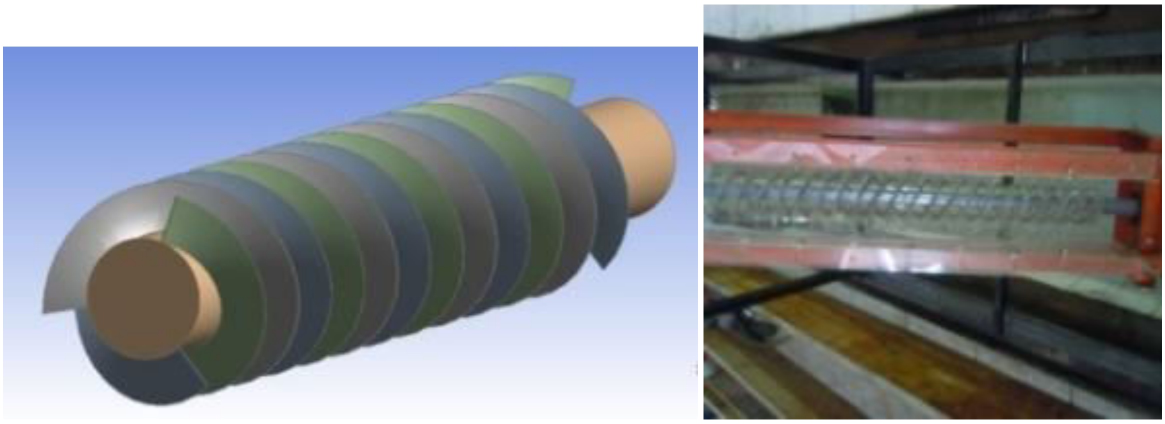

Figure-1. Model of three-bladed Archimedes Screw turbine[15].

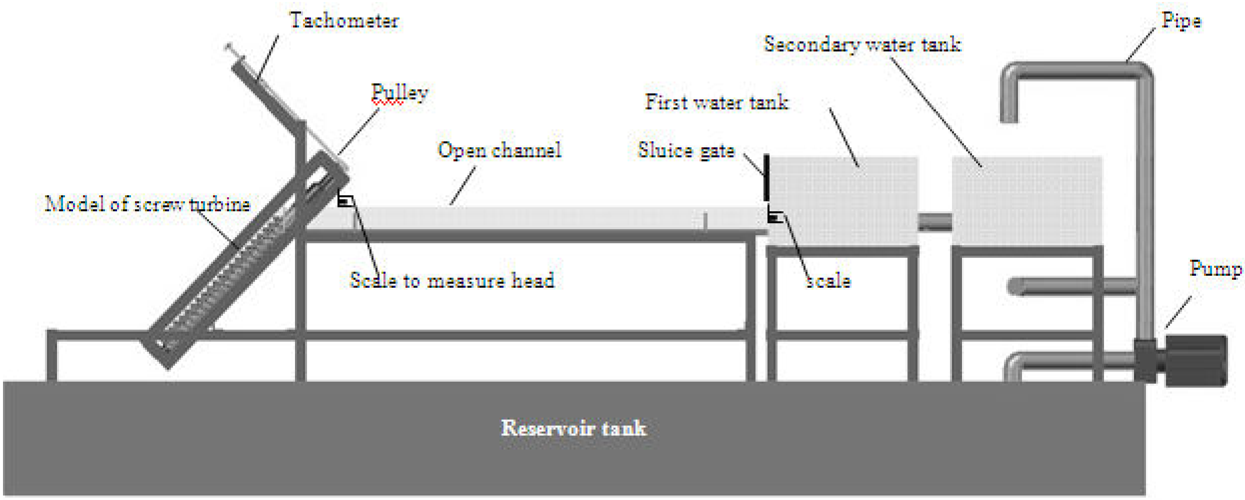

Figure-2. Archimedes screw turbine instalation[15].

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Parameters of screw turbine model:

Parameter	Value	Description
R_o	0.055 m	Outer radius
R_i	0.030 m	Inner radius
S	0.132 m	Pitch
N	3	Number of blades
m	21	Number of helix turns
β	30°	Thread angel
λx	0.059	Normalized volume/turn
α	25°, 35°, 45°	Turbine shaft declivity
y	$1/2R_o$, $2/3R_o$, $1R_o$	Characteristic length
c_a	(0.3, 0.4, 0.5) m/s	Inflow velocity

The equation that used in the data analyzed is:
Hydraulic power of screw turbine,

$$P_{hyd} = \rho .\ g.\ Q.\ H = \rho .\ g.\ Q.\ m.\ \Delta y \quad \text{(Watt)} \qquad (1)$$

$\rho$is water density, g is gravitation, Q is the flow rate, m is number of helix turn, and Δy is delta head among the blades.

The power of screw turbine (P) is torsion (T) is equivalent with angular velocity (ω), it shows as the followingequation :

$$P = T.\ \omega = \mathrm{T}.\frac{2\pi n}{60}. \quad \text{(Watt)} \qquad (2)$$

Efficiency of screw turbine is finally calculated :

$$\eta = \frac{p}{p_{hyd}}.100\ \% \qquad (3)$$

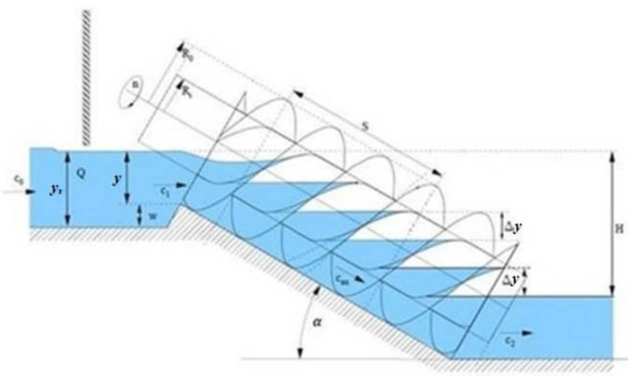

Figure-3. Flow model on Archimedes screw turbine blade [6].

RESULT AND DISCUSSIONS

The performance of three-bladed Archimedes screw turbine was recognized through test data and data analyzed by using equation 1, 2, and 3. Relationship of turbine rotation and hydraulic power on characteristic length variable (y) of 1Ro, and inlet velocity (c_o) of 0.5 m/s is shown in Figure-4. It seems that the fastest rotation the larger its hydraulic power. The largest of hydraulic power of 16.97 is occurring on a shaft's slope (α) of 45^0, and rotation of 350 rpm. It happens because of the concept of hydraulic power in equation 1, where the flow rate (Q) is influenced by volume per bucket that equivalent with rotation (Nuemberk Dirk M.,Rorres 2013).

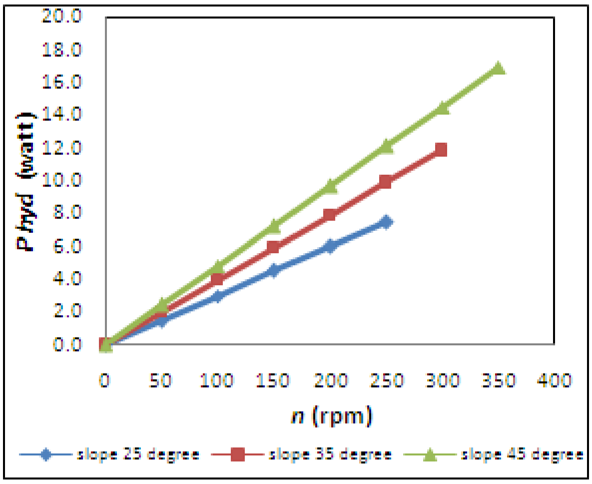

Figure-4. Rotation vs. hydraulic power at $y = 1R_o$ andc_o = 0,5 m/s.

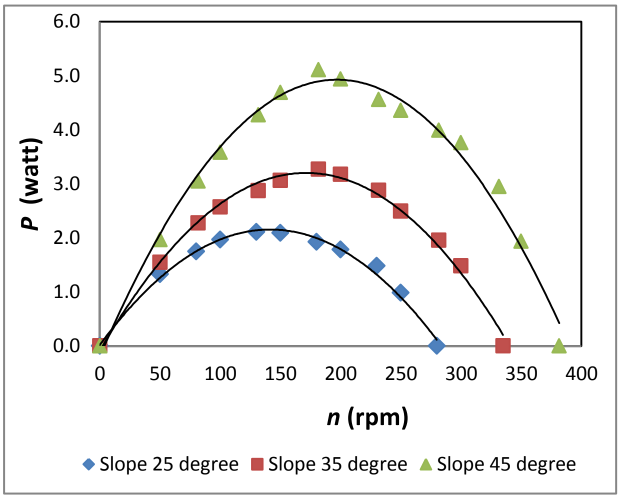

Figure-5. Rotation vs. output power of screw turbine at $y = 1R_o$andc_o = 0,5 m/s.

Output power of three-bladed Archimedes screw turbine is performed based on the relationship between output power and rotation. Figure-5 shows the relationship of output power and rotation with characteristic length variable (y) of 1Ro and inlet velocity (c_o) of 0.5 m/s. The high output power of screw turbine reach 5.11 watt with shaft's slope (α) of 45^0 and rotation of 182 rpm. For the shaft's slope (α) of 35^0 and rotation of 182 rpm, the output power reach 3.26 watt. For the shaft's slope (α) of 25^0 and rotation of 130 rpm, the output power reach 2.11 watt. It showed that the largest shaft's slope the fastest shaft's rotation, therefore output power by turbine become greater. In otherwise, shaft's rotation would determine the value of torsion according to equation (2).

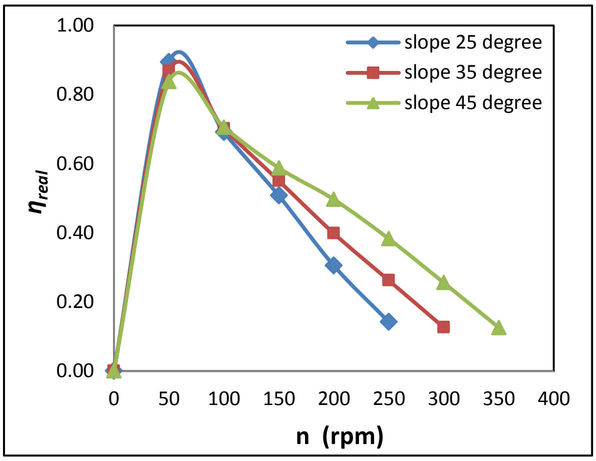

Figure-6. The effect of turbine shaft slope toward the turbine efficiency and turbine rotation.

The performance of three-bladed Archimedes screw turbine depends on its efficiency through equation (3). Figure-6 shows the relationship between efficiency and rotation in each shaft slope of 25^0, 35^0, and 45^0. The highest efficiency is 89% that occur in rotation of 50 rpm, shaft's slope of 25^0 and characteristic length of 1Ro. For efficiency of 87%, rotation of 50 rpm and shaft's slope of 35^0. For efficiency of 84%, rotation of 350 rpm and shaft's slope of 45^0. The highest rotation of the turbine is 350 rpm with shaft's slope of 45^0. The similar efficiency of 13% was found on the shaft's slope of 25^0, 35^0 and 45^0, with rotation of 250 rpm, 300 rpm, and 350 rpm.

Inlet velocity of characteristic length (y) of 1Ro is 0.5 rpm. The shaft's slope, characteristic length, inlet velocity are important factors in generating power of the Archimedes screw turbine. The result of this experiment shows the performance of screw turbine will be maximized if the shaft's slope (α) of 25^0 and rotation of 50 rpm, which automatically become better in low head and rotation operation.

CONCLUSIONS

From the result of this research could be drawn some following conclusions:

a) The largest of hydraulic power occurs in the shaft's slope (α) of 45^0 and rotation of 350 rpm, that is 16.97 watt. Due to flow rate (Q) is influenced by volume per bucket that equivalent with rotation.
b) The largest of screw turbine power occurs in the shaft's slope (α) of 45 and rotation of 182 rpm, that is 5.11 watt. Due to the shaft rotation affect torsion.The highest efficiency is 89% that occurs on a shaft's slope of 25^0, a rotation of 50 rpm, and characteristic length (y) of 1Ro.
c) The shaft's slope, characteristic length, inlet velocity are the important factors in generating power of the Archimedes screw turbine. The experiment to show that the performance of Archimedes screw turbine is maximum if the shaft's slope is lower.

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